Improving crop resistance: A new plant breeding technique borrows from the past

by Kevin Conway

Plant breeder in Africa

Reducing pesticide use
Health and economic benefits

Given enough time, everything that is old will become new again. This cliché holds true for population breeding, an ancient crop improvement technique in which an entire population of plants is screened for the small minority with the best traits. The technique dominated plant breeding for millennia, but fell into disfavour in the early 1900's as word of Gregor Mendel's experiments with pea plants spread. Pedigree breeding techniques and the high yielding pure line crops that launched the Green Revolution owe their existence and success to Mendel, a diligent Austrian monk and the "father of modern genetics", whose work in the mid-1800's was ignored for 35 years.

But crop scientist Raoul Robinson believes the single-mindedness with which pedigree breeding has been adopted around the world is largely responsible for modern agriculture's addiction to chemical pesticides. "Plant breeding has four broad objectives: to improve the yield, the quality of crop product, the agronomic suitability, and the resistance to pests and diseases," he stated at a recent meeting held at the International

Development Research Centre (IDRC).

According to Dr. Robinson, modern plant breeding has been "spectacularly succesful in the first three of these objectives. This is demonstrated by very large increases in agricultural production, and the fact that the world is still able to feed itself in spite of massive increases in the size of the population." However, breeders have generally fared much worse with the fourth goal. In some cases, pedigree breeding has actually reduced the level of resistance to pests. "This is why we use chemical pesticides in such large quantities," he explains.

Reducing pesticide use

Dr. Robinson says the key to reducing the amount of pesticides entering our food chain is to refine the population breeding approach used by our ancestors. He points to the success of recent work in Mexico as an example of what can be accomplished. With funding from IDRC, Robinson and a team of researchers from the Colegio de Postgraduados in Montecillos, Mexico and the University of Guelph in Canada used mass selection techniques to dramatically increase the yield of black beans — from 400 to 1,500 kilograms per hectare — without the help of pesticides.

"Our best lines are now outyielding the commercial lines. The commercial lines have been sprayed and ours have not," says Dr. Robinson. His technique, called "horizonal resistance breeding", relies on the genetic variability present within the landraces of Mexican beans. (A landrace is a genetically diverse, cultivated plant population.) Unlike their genetically uniform pure line cousins, he explains, individual plants within a landrace display varying degrees of resistance to pests: some are highly susceptible to parasites and usually die, most are moderately susceptible to parasites but can still produce seed when attacked, and others are highly resistant and tolerate parasitism well. Through careful selection, the plant breeding team simply shifted the resistance displayed by the majority of plants towards those individuals with more resistance.

Health and economic benefits

Results of this Mexican-Canadian collaboration have important implications for small scale farmers throughout the South. Breeding techniques that reduce the need for pesticides offer both health and economic benefits, especially in rural communities. For example, the improper use of pesticides is a serious health threat to agricultural workers and a major source of water pollution.

Mass selection also offers long-term benefits of broader significance to all of humanity. Today, small farms are the repository of much of the agricultural diversity on Earth. Any breeding technique or program that encourages farmers to preserve and enhance this diversity may help to safeguard the genetic pool from which future improvements in crops will likely come.

Kevin Conway is IDRC's senior corporate writer.

Sidebar:

Population Breeding and Integrated Pest Management

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Breeding a Better Bean: The Horizontal Resistance Approach

by Douglas Powell

Mexican farmers: sowing seed

Researchers in Mexico and Canada have dramatically boosted the yield of a major Mexican food crop using an unconventional breeding technique that harnesses the power of multiple resistance genes to protect against a range of plant pathogens.

Using horizontal resistance breeding, scientists from the Colegio de Postgraduados in Montecillos, east of Mexico City, — in partnership with the University of Guelph in Canada — have more than tripled the yield of locally grown black beans — without the help of pesticides.

Different Kinds of Resistance

In 1963, J.E. Vanderplank, a South African plant pathologist, coined the terms "horizontal" and "vertical" resistance to describe the different kinds of genetic resistance found in crop plants. Vertical resistance, which involves a single gene, is a temporary form of genetic resistance that breaks down as new pathogens appear on the scene. Horizontal resistance, which involves many genes, is a more durable form of resistance to disease or insects.

To protect crop plants from parasites, most breeders use classic Mendelian breeding techniques to transfer a single gene from a wild plant into a cultivar (cultivated variety), a process that enhances its vertical resistance. This involves crossing a wild plant with a cultivar to generate a hybrid variety, then backcrossing the hybrid offspring with the cultivar parent for several generations until the hybrid is identical to the cultivar but carries the wild parent's resistance gene.

Failed Objectives

> "[Unfortunately], when plants are being bred for vertical resistance, or they are being bred [to improve] yield and crop quality under the protection of insecticides and fungicides, the level of horizontal resistance tends to decline," says Raoul Robinson, a Canadian crop scientist and member of the IDRC-supported plant breeding team. "We have actually been increasing the susceptibility of many of our crops to their parasites. Most of the [vertical] resistance breeding programs of the twentieth century have totally failed to achieve their original objectives."

Since 1991, Dr Robinson has worked with Dr Roberto García Espinosa, the Mexican project manager, to attempt horizontal resistance breeding in black beans — a process in which the best individuals from each generation are selected and bred with each other. After only two breeding cycles, each cycle lasting about a year in duration, the team achieved yields of 1,500 kilograms per hectare **without using pesticides**. For comparison, the average bean yield in the Mixteca region of Mexico is 400 kilograms per hectare **using pesticides**. This is good news for the approximately 200,000 small-scale farmers in the area, who cultivate over 300,000 hectares, of which 40,000 are beans. Moreover, the breeding techniques developed in Mexico can be used almost anywhere and on most kinds of crops.

"Return to Resistance"

Dr Robinson is the author of *Return to Resistance*, which features a how-to guide for amateur plant breeders interested in selecting for horizontal resistance. In addition, he helped to establish the world's first horizontal breeding club at Universidad Autonoma de Chapingo in March 1995. To date, its 76 members have collected more than 3,000 bean varieties from all over Mexico and are considering launching additional clubs for breeding potatoes, wheat, onions, and peanuts.

Douglas Powell is the Science and Society professor at the universities of Guelph and Waterloo.

Resource Persons:

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Population Breeding and Integrated Pest Management

The work of Raoul Robinson and his Mexican colleague, Dr. Roberto Garcia Espinosa has drawn interest from Latin American practitioners of integrated pest management (IPM). For example, Dr. Robinson was a guest speaker at the Sixth Latin American Congress on Pest Management held in Acapulco, Mexico in October 1996.

"In principle, host (plant) resistance is the most important tool in the practice of integrated pest management," says Dr. Robinson. "As a matter of historical fact, however, cooperation between practitioners of IPM and plant breeders has been minimal."

IPM relies on an understanding of the ecology of crop pests to devise different ways to control pest infestations. Pesticides still have a role in most IPM strategies, although they are used less frequently and often as a last line of defence.

According to Dr. Robinson, breeding for greater pest resistance should be the first consideration in any IPM strategy. "The more that farmers use resistant varieties," he explains, "the less need for spraying and the more that biological controls will be restored. As biological controls are restored, existing levels of resistance will increase in effectiveness." Thus, breeding for greater resistance will make all aspects of IPM even more effective.

Kevin Conway

High Maize Yields Offer Hope for Burundi Farmers

by Andrew Ker and Dunstan Malithano

Dunstan Malithano (left) and research assistant

Burundi, a nation trying to end a devastating civil war, appears to have overcome a different type of threat. Using locally available maize populations, an IDRC-supported research team has developed several high-yielding varieties resistant to the African maize streak virus. This virus is one of the worst of several plant diseases to attack maize, an important staple food here and throughout eastern and southern Africa.

Infested maize leaves

The disease, carried from plant to plant by a leafhopper insect (*Cicadulina spp.*), can decimate an entire maize crop in a severe attack. The disease is characterized by greenish streaks on the maize leaves. Historically, it has been more prevalent at lower altitudes, but in recent years the virus has increasingly affected crops grown at higher altitudes. This may be due to changes in the habits of the leafhopper vector, perhaps because increasing numbers of small-scale farmers are being forced to cultivate maize further up

the hills and throughout the year.

Beginnings

In 1978, ISABU, the Burundi national agricultural research institute, approached IDRC for help in establishing a maize-improvement program. The program's aim was to breed high-yielding maize varieties resistant to streak and other diseases, and adapted to the needs of farmers in the different ecological zones of Burundi. The research team began by collecting and testing a wide range of varieties, both local and foreign, including high-altitude lines obtained from the International Centre for Maize and Wheat Improvement (CIMMYT) in Mexico. However, this material was poorly adapted to local conditions and quickly succumbed to the maize streak virus.

Late-maturing

The highest yielding introductions at the Kisozi maize research station in Burundi (located 2150 metres above sea level) were hybrids bred at a similar altitude at the Kitale station in Kenya. However, these hybrids were generally late-maturing varieties, taking eight or nine months to harvest. Farmers in Burundi preferred varieties that matured in four or five months, which gave them time either to plant another crop after the maize or plant two maize crops a year.

On the Imbo Plain -- located on the floor of the Rift Valley north of Burundi's capital, Bujumbura -- maize varieties adapted to the 800-metre altitude environment were needed. Intensive screening of maize obtained from the International Institute of Tropical Agriculture (IITA) in Nigeria resulted in the identification of one variety adapted to the Imbo Plain and preferred by farmers. IITA had also developed several streak-resistant breeding lines, although none of them were suitable for Burundi conditions.

Improving Local Maize

In 1985, Dr Dunstan Malithano, a Malawian researcher who had previously worked for IDRC in Mozambique, joined the team. He reorganized the breeding program to place greater emphasis on improving local maize populations, rather than making selections from exotic varieties and developing hybrids. Previous work had shown that maize obtained from other countries often fared poorly in Burundi and that farmers did not accept them. By contrast, new varieties based on local populations would be readily accepted by farmers and consumers. This approach also meant that farmers would not have to buy hybrid seeds every year.

It turned out that farmers did not have to wait long before receiving improved seed. Within two years of beginning the new approach, superior maize varieties were distributed, while the researchers continued developing better and higher yielding varieties. By 1989, the team had developed three high-yielding varieties resistant to streak disease: "Mugamba I" and "Isega I" for the high and medium altitude areas, and "Imbo I" for the lakeshore and Imbo plains. Imbo I was also found suitable for beer brewing, replacing barley in the Burundi Brewery.

Distribution Bottleneck

The brewery played a key role in getting the seed into the hands of farmers. Burundi lacked a seed-production facility, creating a bottleneck when it came distributing the new varieties. To meet demand, Dr Malithano negotiated with the brewery to multiply his improved maize varieties. After one growing season, the brewery had produced enough seed to distribute to a limited number of farmers, who in turn generated 43 tonnes of seed. The new variety was then sold to farmers throughout the Rift Valley, on the condition that part of their crop be sold back to the brewery for further distribution or brewing purposes.

By 1994, it was estimated that 80% of all Burundi maize growers had adopted the streak-resistant varieties

and were growing them successfully. In addition, there was increasing interest in the new maize varieties from other neighbouring countries such as Kenya, because of the rapid spread of streak disease there. An important legacy of the maize improvement program is that Burundi researchers have been trained to take over the breeding program completely.

Andrew Ker was the senior IDRC program officer responsible for crops and cropping systems projects in eastern and southern Africa, from 1987 to 1992. Dunstan Malithano served as scientific advisor for IDRC on the Burundi maize improvement program.

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Additional resources:

CIA World Fact Book: Burundi

International Centre for Maize and Wheat Improvement (CIMMYT) Internet Site

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Integrated Pest Management for Colombian Small Farmers

by David Mowbray

Integrated Pest Management (IPM) test plot in Colombia

Gerardo Sota farms on some of the most difficult terrain on earth -- the precipitous slopes of the Andes mountains in Colombia. No farm machine can negotiate the steep hillsides and narrow furrows. Every carefully terraced row must be plowed by hand. Every bean pod, ear of corn, or potato that grows is picked or dug by hand. He, his sons, and now his grandsons work year-round to keep their hectare-and-a-half farm productive.

Despite the demanding conditions for farming, Sota loves his land. To him, every square metre is precious and, if treated well, will give something back. "Agriculture is my profession," Sota explains. "My father taught me how to farm the land. Farming is what I most like doing."

Staple Food

Sota grows potatoes, carrots, corn, and -- most importantly -- beans. Beans are a vital food crop in the Andean region of South America. In Colombia, Ecuador, and Peru, beans provide both calories and protein in the diets of the rural poor. Many Andean families eat beans three times a day. By the turn of the century, demand is expected to exceed supply by 30%. Beans have been grown in rotation with corn on the mountain slopes for thousands of years. The stalks left from the harvested corn form climbing poles for the beans. The nodules on the bean roots take nitrogen from the air to fertilize the soil for the next corn crop.

Gerardo Sota had always farmed without using chemical pesticides. More than 20 years ago, his father had warned him of their dangers. For years, he saw no need for them. But 15 years ago, the situation changed. "I started to use them ever since I lost a bean crop," he recalls. "The crop was attacked by a pest. The

beans had already developed pods and suddenly that pest attacked. The pods turned black."

Vicious Cycle

Sota lost his crop and any chance of making ends meet that year. He determined never to let it happen again, deciding that the risk of sickness from the insect spray was worth it. Now Sota and the other bean farmers of the Andean region are caught in a vicious cycle of ever increasing pesticide use.

The indiscriminate use of the sprays killed not only the pests but beneficial insects too. As a result, what had been insignificant pests, such as the leafminer, were left with no natural enemies and began devastating bean crops. So farmers had to spray more. Today, in some bean-growing areas of the Andes farmers spray every week.

> "We farmers have a fault," explains Sota. "If we see that a tablespoonful works to kill the insects, then we say, 'Well let's add another tablespoonful so it will be even more effective!'"

Cause for Alarm

Practices such as these were alarming Dr Cesar Cardona, an entomologist at CIAT, the International Centre for Tropical Agriculture based in Cali, Colombia. "We detected a very serious situation of insecticide abuse among small bean farmers in the Andes of Colombia, Ecuador, and Peru. We found that the levels are extremely high, that the crop is becoming uneconomic because of the excessive use of chemicals," Cardona says.

In the past, Cardona himself had advocated the use of pesticides to improve crop yields. "I was trained to use pesticides 20 or 25 years ago. I did it for a while but I have been convinced that we can produce safer products at lower cost without using so many chemicals."

Participatory Research

Cardona determined that a program of integrated pest management, a strategy that had worked with many other crops to reduce the need for spraying, could work on the tiny mountainside plots if enough farmers could be convinced to use it. The key to his idea was to involve farmers in the research itself.

With funding from IDRC and the cooperation of the national agricultural research systems of Colombia, Ecuador, and Peru, Dr Cardona initiated a program of farmer participatory research to find out which insect management strategies would work.

Implementing IPM

The whole goal of integrated pest management (IPM) is to reduce pesticide use to the minimum necessary by introducing practices such as destroying crop residues that harbour the eggs of next season's pests. The crops are regularly inspected and then sprayed using only the chemical that is appropriate for the particular pest. The various components of the IPM approach had worked well in other situations but this was the first time anyone had tried to use them with small farmers in such difficult terrain and with a crop like beans.

Cardona's research team selected farmers willing to set aside some of their fields for the tests. Each farmer had two similar plots -- one which he or she maintained in the usual way, spraying whenever it was considered necessary. In the adjacent plot, the scientific teams used the more environmentally sound, integrated approach.

If IPM techniques worked, the scientists thought the farmers participating in the tests would see the results

right away. For the most part that was true. But the researchers also learned from the farmers. Not all the ideas tested at the research stations were acceptable to the farmers. For example, the scientists thought that sticky yellow traps coated with fuel oil would reduce the insect population. To trained scientific eyes they did kill millions of bugs. But the scientists had not considered the extra work involved in maintaining the traps on the steep mountain slopes. The extra trips down the mountain to town to get new oil, and the cleaning of the traps demanded too much labour to be worthwhile. Moreover, although the traps were full of dead bugs, the farmers still saw thousands of live insects on their bean plants.

Simple Monitoring Techniques

Another part of the IPM strategy is to monitor the bean plants for signs of insect infestation. But many of the farmers have little formal education. The careful record keeping and arithmetic that served well at the research stations could not succeed with the farmers. So the researchers who were working with farmers on the test plots in Ecuador came up with a straightforward monitoring and counting technique that every farmer could understand and use. It required just a glass jam jar and a pocketful of beans. For every damaged bean pod the farmer spots, a bean goes into the jar. If the jar fills slowly, there is no need to spray.

Cesar Cardona says the results on the test farms throughout the region are impressive. Crop quality has been maintained, pesticide use dramatically reduced and the profitability of the bean crop increased because the farmers spend less on pesticides.

> "If most of them start implementing IPM, insect population levels will gradually decrease in the area," Cardona says. "Now they do see the better economic returns and lower cost. There is no need to use so many chemicals. They can produce the same with at least 60 or 70% less insecticides without losing a penny -- or even make more money."

Everybody Wins

In the towns and on the farms of the Andes, it is an approach by which everybody wins. Consumers get a healthier product, farmers expose themselves and their families to far fewer potentially damaging chemicals, and the land carries a lower toxic burden into the future. Eventually, it appears possible to restore the equilibrium that existed thousands of years ago when the indigenous people of the region first understood the close relationship between beans and corn and never used a drop of insect spray.

The next phase of the project will develop methods of getting the technology from the test farms to everybody's farm. Gerardo Sota does not think this technology transfer will be especially difficult. "It favours farmers and it's less risky for us not to use toxic chemicals. Consumers are in less danger of being harmed by these products. I would recommend it because it gives such good results."

David Mowbray is an Ottawa-based film-maker and writer, reporting from Colombia.

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The CIAT-Canada Connection

Canada has had strong links with CIAT, the International Centre for Tropical Agriculture based in Cali, Colombia for a quarter of a century. CIAT is one of 16 international research centres in the developing world devoted to improving food security for the world's most impoverished people. It was founded in 1967 and since 1971 both the Canadian International Development Agency and IDRC have been major donors to the operations and the research programs of the renowned Centre.

Robbin Ruggles, a Canadian recently on CIAT's professional staff, points out that Canada was instrumental right from the beginning in getting CIAT's renowned cassava improvement program off the ground. Cassava, a root crop that originated in South America, now serves as a food staple for half a billion people, primarily in South America and Africa.

Canadians Benefit

Canadians farmers have also benefitted directly from work done at CIAT. In addition to its research work to improve beans, cassava and other crops, CIAT holds one of the world's major germplasm collections in its gene bank. A navy bean variety called ExRico 23 was developed by the national research program of Colombia. CIAT introduced it to North American farmers. It is resistant to white mould disease and its use has saved Canadian farmers millions of dollars. Other CIAT bean lines with resistance to potato leaf hoppers will soon find their way onto Canadian farms.

As for the future Ruggles feels there are areas for cooperation between Canada and CIAT that remain to be tapped. He would like to see CIAT linked with more agriculture and environment departments at Canadian universities. "CIAT can act as a bridge for Canadian universities to partner with national organizations in developing countries."

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